MCEN 5151-002 Flow Visualization

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Team Second Project Report

The Making of "Mind your Head"

Figure I: "Mind your Head" Thumbnail

(I) Project Background

The image shown in Figure I above was collected from a video taken for the Team Second project; part of the Flow Visualization curriculum at the University of Colorado Boulder. The goal of the project was to create a controlled flow scenario which actively and accurately demonstrates a flow phenomenon in a controlled setting with artistic aesthetic in mind. The video, found on Vimeo here is an attempt to investigate particle behavior in a vortex and the impact of solid particles on the momentum of a fluid. This experiment was created by dying pearl couscous red, drying it, and dropping it into a plastic bottle of water after creating a strong water vortex with a spoon. As can be seen in the video, the behavior of the particles is dependent on not only the geometry of the couscous, but also, it's water absorbance (impacting buoyancy) and the dynamics of the vortex. The end result is somewhat reminiscent of Brownian motion, though in a controlled setting. The following sections go into detail on some of the physics behind this phenomenon as well as how this video was created.

(II) Image Flow

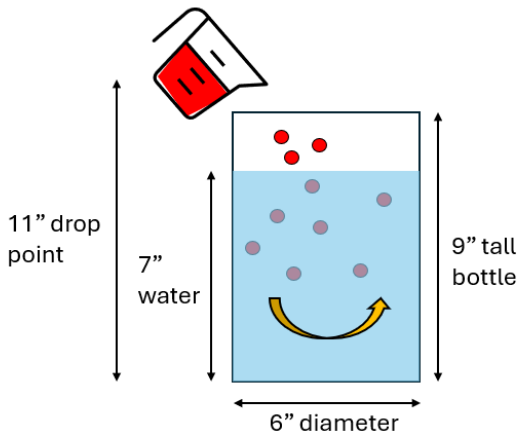


Figure II: Set-up Diagram

The image itself was captured in a brightened room (natural lighting) next to a window, with the camera providing a side view of the plastic bottle as shown in Figure II above. The 16:9 video captures a physical area of 14" x 7.875" to capture as much information as possible without including distracting features such as the top of the bottle or the background. Approximately 1/8th of a cup of red dyed couscous was dropped about 11" above a plastic bottle of recently stirred tap water. The video was initially taken right as the water was being stirred, as can be seen in the video, and afterwards the stirring was cropped to only include post-stir footage. The video captures the behavior of the couscous following the introduction of a vortex.

(III) Flow Physics

Ultimately, the vortex is the result of centrifugal forces pushing against the induced centripetal momentum of the fluid. Naturally, this velocity distribution leads to a low particle velocity (and density) in the center of the vortex and a high particle velocity at the outskirt of the vortex. The velocity distribution can be visualized in Figure III below:

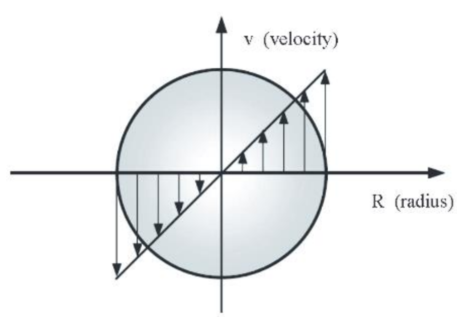
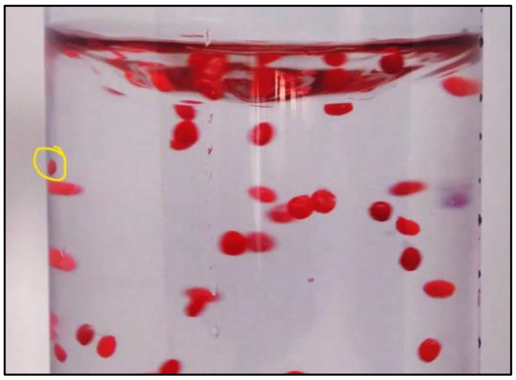


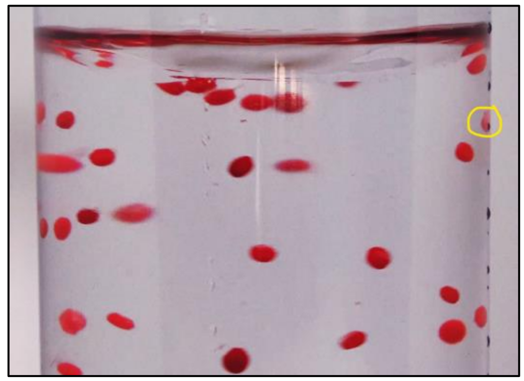
Figure III: Velocity distribution in a vortex (Meyl, 2012)

This leads to a visible “dip” in the center of the water vortex as the water is pushed towards the outside of the container. Using this information combined with the video it is possible to calculate the velocity of the particles, the surface energy of the fluid flow, and the rate of energy dissemination.

We can calculate the velocity of the flow by calculating the rotational velocity of the outermost particles in the vortex. This is best found in this example by going frame by frame on a section of video to see how long it takes for a particle to go from one side of the bottle to the other.



Start Frame



5 Frames (1/6 s) Later

Figure IV: Velocity Calculation

Using the method shown in Figure IV above, the sampled velocity of an outermost particle was found to be $1/6^{th}$ of a second to go a half circumference (or 9.43”). Given the framerate of the video is 30fps, and 5 frames passed from one end to the other, the particle (and estimated outer velocity) of the water is 9.43”/(1/6 s)=56.55in/s=1.44m/s. We can use this information to calculate the surface energy of the fluid flow using the below equation (Poplevin et al., 2024).

$$E_s = \int V^2 dS \text{ where V is the fluid flow velocity}$$

$$dS = Rd\emptyset dz = \sqrt{(0.15m^2 \sin^2(0.48) + 0.15m^2 \cos^2(0.48))} * 0.48m * 0.18m = 0.013$$

$$E_s = \int 1.44^2 * 0.013 = 0.027 * (2\pi * 0.08 * 0.18 + 2\pi * 0.08^2) = 0.0035J$$

As such the surface energy of this vortex flow is approximately 0.0035J at the start of each transition, which takes about 8 seconds to noticeably disseminate without outside influence. Note that without the couscous the water vortex takes longer to disseminate as it has less mass to displace and move, though this is not easy to measure without a visual reference.

(IV) Visualization Techniques

The experimental set-up follows the diagram shown in Figure II, taking place in a large room the afternoon of a sunny day next to a window. The plastic bottle was created from an old Kroger orange juice bottle, of which I took the stickers off, cleaned, and cut the top off. I placed the bottle on white posterboard, and I curved white posterboard behind the bottle where the camera was pointing. I filled the bottle with 7" of tap water and stirred with a table-spoon until a visible dip was formed in the water before dropping any couscous in. To dye the couscous (for a more interesting video) I slightly heated up 2 cups of water in a pan, dropped ¼ cup of Private Selection Pearl Couscous into the water, and put 3 drops of red Satin Ice food coloring into the water and stirred for 2 minutes. Then, I poured the couscous through a strainer and put them in the oven at 250 degrees Fahrenheit for 15 minutes. Following this I was able to recover 1/8th of a cup of dried red couscous. When ready, I placed the camera on a 10" tripod on the ground about 20 inches from the bottle. As shown in the video, I started by stirring with a spoon and starting the video, then poured in the couscous and watched the momentum decay. After waiting for the particles to slow down and restirring a few times I ended the video.

(V) Photographic Techniques

The video captures an area of approximately 14" x 7.875" provided by the camera approximately 10" from the ground. The video was taken on a Fujifilm XT30 II digital mirrorless camera with f/5.6 for a higher shutter speed. The unedited video size is 3840x2160 and the edited video size is 1920x1080. The video was taken at 30 fps sampled from a 1/250 shutter speed with an ISO of 1250 was used with an XC15-45mm interchangeable lens and 44.5mm focal length. This shutter speed was chosen for clarity and the ISO was chosen to counteract the low light conditions that came with the faster shutter speed while also avoiding grain. A dynamic range of 400% was also used for exaggerated color as well as a natural white balance (built in setting) to "whiten" the lighting. In post-processing, using Windows ClipChamp, the contrast was slightly increased, and a slight grain was added on top of the Fujifilm Velvia simulation applied by the camera. I trimmed the video to only include portions where the couscous was moving fairly quickly, and it was because of this software that the video resolution was decreased. These choices were made to make a stark contrast between the red couscous and white background for the best visibility and maximum interest. The audio was created using Brev.ai to make for a more interesting video while complying with copyright.

(VI) Conclusion

"Mind your Head" to me provides a clear view of density and velocity distributions in a vortex, and it is particularly interesting to see how some particles will move towards the outside of the flow, some towards the inside, and some up and down. Ultimately, I like how the flow is somewhat mesmerizing to watch in that it draws your eye towards both a single particle and the entire flow. Otherwise however, I don't particularly like the end result as I wish I could have experimented with the coloring, resolution, and cropping of the video more. I believe the color scheme is a bit of a letdown aesthetically, and the camera should have been in portrait mode to capture the most action over the white background. In the end I believe the fluid physics were shown pretty clearly and that I fulfilled my initial intent, but I definitely see areas I could improve after creating this first video. In the future I would like to further explore the use of different liquids, dyes, stirring techniques, and containers to make a more interesting piece.

Bibliography:

Meyl, K. (2012). About Vortex Physics and Vortex Losses. Journal of Vortex Science and Technology, 1, 1–10. https://doi.org/10.4303/jvst/235563

Poplevin, A. V., Levchenko, A. A., Likhter, A. M., Filatov, S. V., & Mezhov-Deglin, L. P. (2024). Vortex Motion on the Surface of Shallow and Deep Water. *Journal of Surface Investigation: X-Ray, Synchrotron and Neutron Techniques*, *18*(3), 717–725. https://doi.org/10.1134/S1027451024700368